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Patentanmeldung Nr. Patent application No. Demande de brevet n°

02075209.3

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Der Präsident des Europäischen Patentamts; Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets p.o.

R C van Dijk

Anmeldung Nr:
Application no.: 02075209.3
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Koninklijke Philips Electronics N.V.
Groenewoudseweg 1
5621 BA Eindhoven
PAYS-BAS

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(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Optical scanning device

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Optical scanning device

The present invention relates to an optical scanning device for scanning a first information layer, a second information layer and a third information layer by means of a first radiation beam having a first wavelength (λ_1), a second radiation beam having a second wavelength (λ_2), and a third radiation beam having a third wavelength (λ_3), respectively, said first, second and third wavelengths being substantially different, the device comprising: (a) a radiation source for emitting said first, second and third radiation beams, (b) an objective system for converging said first, second and third radiation beams beam on the positions of said first, second and third information layers, and (c) a phase structure arranged in the optical path of said first, second and third radiation beams between said radiation source and the positions of said first, second and third information layers, the phase structure comprising a plurality of phase elements of different heights, forming a non-periodic stepped profile of optical paths in the beam. One particular illustrative embodiment of the invention relates to an optical scanning device that is capable of reading data from three different types of optical record carriers, such as compact discs (CDs), conventional digital versatile discs (DVDs) and so-called next generation DVDs.

The present invention also relates to a lens for use in an optical device for scanning a first, second and third type of optical record carrier with a beam of radiation of a first wavelength, a second wavelength and a third wavelength, respectively, the three wavelengths being substantially different, the lens being provided with a phase structure arranged in the path of the radiation beam, the phase structure comprising a plurality of phase elements of different heights, forming a non-periodic stepped profile of optical paths in the beam.

A "wavefront modification" is a modification of the shape of the wavefront of a radiation beam. Such modification may be of a first, second, etc. order of a radius in the cross-section of the radiation beam if the mathematical function describing the wavefront modification has a radial order of three, four, etc., respectively. Wavefront tilt or distortion is an example of a wavefront modification of the first order. Astigmatism and curvature of field and defocus are two examples of a wavefront

modification of the second order. Coma is an example of a wavefront modification of the third order. Spherical aberration is an example of a wavefront modification of the fourth order. It is noted that some wavefront modifications, such as wavefront tilt, astigmatism and coma, are dependent on a direction in the cross-section of the radiation beam. Some wavefront modifications, such as defocus and spherical aberration, are independent on a direction in the cross-section of the radiation beam. For more information on the mathematical functions representing the aforementioned wavefront modifications, see, e.g. the book by M. Born and E. Wolf entitled "Principles of Optics," pp.464-470 (Pergamon Press 6th Ed.) (ISBN 0-08-026482-4).

There is currently a need in the field of optical storage for providing optical scanning devices having one optical objective lens for scanning a variety of different optical carrier carriers using different wavelengths of laser radiation, such as a first disc of the so-called DVR-format, a second disc of the so-called DVD-format and a third disc of the so-called CD-format.

For instance, a typical problem is to make an optical scanning device compatible with all currently existing disks, i.e. DVD-format discs and CD-format disc and DVR-format discs readout, by means of a first radiation with a first wavelength that equals 405 nm, a second radiation with a second wavelength that equals 650 nm (to read dual-layer DVD), and a third radiation with a third wavelength that equals 785 nm (to read CD-R). Due to this plurality of wavelengths, designing a non-periodic phase structure generating predefined wavefronts for each wavelength configuration is difficult. The reason for this is that in designing a non-periodic phase structure (NPS) one makes use of the fact that the phase introduced by a step height h is different when the wavelength is different. For two wavelength such a structure allows for rather simple designs.

It has previously been proposed in, for example, the European Patent application filed on 05.04.2001 with the application number EP 01201255.5, to provide optical scanning devices that are capable of scanning data from Blue-DVDs, Red-DVDs and CDs with laser radiation of different wavelengths, whilst using the same objective lens. Furthermore, it is known in EP 01201255.5 to provide an NPS suitable for three wavelength simultaneously is discussed.

Whilst the previously proposed scanning devices provide a solution for situations where three different optical media are illuminated with three associated different wavelengths of light using the same objective lens, they do not provide

assistance in providing NPS structures easy to design and manufacture for fixed values of the wavelengths. As a result, the known NPS becomes complex, requiring the making of relatively high steps.

Accordingly, it is an object to an optical scanning device which has a single optical objective lens for scanning a variety of different optical record carriers using at least three radiation beams having three mutually different wavelengths.

It is also an object of the invention to provide an objective lens suitable for at least three different wavelengths having a simple structure and generating predefined wavefronts at the three wavelengths.

In accordance with a first aspect of the invention, there is provided an optical scanning device as described in the opening paragraph wherein, according to the invention, said phase structure is made of a birefringent material and in that said stepped profile is designed so as to introduce a wavefront modification in at least one of said first, second and third radiation beams and such that at least two of said first, second and third radiation beams have mutually different polarizations. It is worth noting that "flat" as used herein only implies that after taking modulo 2π of the wavefront, the resulting wavefront is constant, hence the non-periodic phase structure only introduces a constant phase offset. The term "flat" does not necessarily imply that the wavefront exhibits a zero phase change. It is also worth noting that, where the term "approximate" or "approximation" is used herein, that it is intended to cover a range of possible approximations, the definition including approximations which are in any case sufficient to provide a working embodiment of an optical scanning device serving the purpose of scanning different types of optical record carriers.

An advantage of forming the phase structure from a birefringent material and with such design is to solve the problem of compatibility mentioned above by using the polarisation property of the radiation beams, i.e. the orientation of the polarisation of the three beams do not all have the same orientation. Consequently, for the NPS there is now an additional parameter which can be used in defining the structure giving rise to more design freedom. The phase introduced by a step height h made of a material having refractive index n at wavelength λ is given by

$$\Phi = 2\pi \frac{h(n-1)}{\lambda} \qquad (1)$$

Consequently, when the wavelength changes the phase introduced by a step changes. Furthermore, when chancing the polarisation and thus changing the refractive index also a change in phase introduced by the step is generated. Combining both effects for the three wavelengths system, designing NPS's generating predefined wavefronts for each wavelength is possible with relatively simple stepped structures.

It is noted that, by virtue of the phase structure according to the invention, it is possible to scan optical carriers with a plurality of different radiation wavelengths, which in turn means that it is possible to provide a single device for scanning a number of different types of optical record carriers.

Another advantage of forming the phase structure according to the invention is to make a phase structure with less amplitude in the height of the steps than in the known phase structure as described in EP 01201255.5.

In accordance with a second aspect of the invention, there is provided a lens as described in the opening paragraph wherein, according to the invention, said phase structure is made of a birefringent material and in that said stepped profile is designed so as to introduce a wavefront modification in at least one of said first, second and third radiation beams and such that at least two of said first, second and third radiation beams have mutually different polarizations.

The objects, advantages and features of the invention will be apparent from the following, more detailed description of the invention, as illustrated in the accompanying drawings, in which:

Fig. 1 is a schematic illustration of components of an optical scanning device according to one embodiment of the invention,

Fig. 2 is a schematic front view of an objective lens for use in the scanning device of Fig. 1;

Fig. 3 is a cross-sectional view along the line AA shown in Fig. 2, and

Figs. 4 to 6 are three schematic illustrations of an objective lens for use in the scanning device of Fig. 1 for operating in three respective modes.

Fig. 1 is a schematic illustration of components of an optical scanning device according to one embodiment of the invention. This device is similar to the scanning

device described in EP 01201255.5 which description is incorporated herein by reference.

First embodiment (or "embodiment 1")

Consider a birefringent material having an extraordinary refractive index of n_e=1.5 and an ordinary refractive index n_o=1.62 These values are typical for UV curable birefringent polymer material. For the moment we neglect the change in refractive index due to difference in wavelength. The birefringent NPS is aligned in such a way that when the polarisation is the light is in the x-direction (p_e) then n_e is selected and when polarised in the orthogonal y-direction (p_o) then n_o is selected. Consider the case where the three wavelengths are given by λ_1=405nm, λ_2=650nm and λ_3=785nm.

We consider first the explicit embodiment discussed in EP 01201255.5 (HD-DVD, DVD, CD compatibility) (see appendix A). Hence we want to design a NPS having no effect for λ_1 and for λ_2 and generating a spherical wavefront for λ_3. We let the steps of the NPS be such that they introduce a phase which is an integer multiple of 2π in the λ_1 configuration. Depending on the polarisation chosen for the λ_1 configuration (or "first configuration" or "first mode") we find that this height must be for p_o:

$$h_{405}^{o} = \frac{\lambda_1}{n_o - 1} = 0.653\,\mu\mathrm{m} \qquad (2)$$

and for p_e:

$$h_{405}^{e} = \frac{\lambda_1}{n_e - 1} = 0.810\,\mu\mathrm{m} \qquad (3)$$

In Table I the step height giving rise to a phase step of 2λ in each configuration is tabulated. In Table II the phase introduced by a step of h^o_{405} or h^e_{405} in the λ_2 configuration (or "second configuration" or "second mode") and the λ_3 configuration (or "third configuration" or "third mode") is given.

Wavelength (nm)	h^o (μm)	h^e (μm)
405	0.653	0.810

650	1.048	1.300
785	1.266	1.570

Table I

	$\Phi(\lambda_2,p_o)/2\pi$	$\Phi(\lambda_2,p_e)/2\pi$	$\Phi(\lambda_3,p_o)/2\pi$	$\Phi(\lambda_3,p_e)/2\pi$
h^o_{405}	0.623	0.502	0.516	0.416
h^e_{405}	0.773	0.623	0.640	0.516

Table II

From these tables it follows that when employing the same polarisation in all these configurations we observe that phase jumps in the λ_3 configuration is approximately π. Consequently, only two substantially different phase steps in this configuration are possible, making the design of a simple NPS, giving rise to flat wavefront for λ_1 and λ_2 and a spherical wavefront for λ_3 difficult. When we employ different polarisations in the three configurations such a simple design is possible. Consider the following case where for λ_1 we use p_o, for λ_2 we use p_e, for λ_3 we use p_e.

In Table III the phase introduced by a step heights mh^o_{405} (m integer) in the λ_2 and λ_3 configuration.

m	$\Phi(\lambda_2,p_e)/2\pi$ mod 1	$\Phi(\lambda_3,p_e)/2\pi$ mod 1
1	0,502	0,416
2	0.004	0.832
3	0,506	0,248
4	0.008	0.664
5	0.510	0.080
6	0.012	0.496

7	0.514	0.912
8	0.016	0.328
9	0.518	0.744
10	0.020	0.160
11	0.522	0.576
12	0.026	0.992

Table III

Table III shows that the phase introduced in the λ_1 and λ_2 configuration, for even step numbers m, are approximately the same. There are then 6 substantially different phase possible in the λ_3 configuration.

We follow now the same approach as in EP 01201255.5 to design the NPS while using now Table III. In Table IV a NPS having 5 zones is tabulated showing a substantially flat wavefront for λ_2 and a spherical wavefront for λ_3. The lens design in tabulated in Appendix A (see below).

Zones [mm]	h [µm]	m	$\Phi(\lambda_2, p_e)$	$\Phi(\lambda_3, p_e)$
0.00-0.40	0.000	0	0.0000	0.000
0.40-0.59	6.530	10	0.1256	1.005
0.59-1.10	5.224	8	0.1005	2.061
1.10-1.20	6.530	10	0.1256	1.005
1.20-1.26	0.000	0	0.0000	0.000

Table IV

Note that due to the extra freedom introduced due to the polarisation in combination with the freedom in choosing n_e and n_o a simple NPS arises having a height difference of only 6.53 microns. The example in EP 01201255.5 (see e.g. Table

4) has a height difference of more than 16 microns. The root mean square of the wavefront aberration (OPDrms) without the NPS in the three configurations is for λ_1 we find OPDrms=17.9 mλ, for λ_2 we find OPDrms=3.2 mλ, and for λ_3 we find OPDrms=134.1 mλ. Hence without NPS readout of CD's is not possible. With NPS we find for λ_1 we find OPDrms=17.9 mλ, for λ_2 we find OPDrms=8.6 mλ, and for λ_3 we find OPDrms=43.8 mλ. Hence with NPS the wavefront aberration is in all cases below the diffraction limit (70 mλ) and readout of all disks is possible now.

Second embodiment (or "embodiment 2")

We now consider the case of compatibility between DVR/DVD/CD. For illustration only we consider a single DVR objective having a free working distance of 1.0mm (see Appendix B). We use the same material for the NPS as in Embodiment 1.

Consider the following case where for λ_1 we use p_c, for λ_2 we use p_c, for λ_3 we use p_o.

In Table V the phase introduced by a step heights m h^0_{405} (m integer) in the λ_2 and λ_3 configuration.

m	$\Phi(\lambda_2,p_c)/2\pi$ mod 1	$\Phi(\lambda_3,p_o)/2\pi$ mod 1
-1	0.377	0.361
0	0.000	0.000
1	0.623	0.639
2	0.246	0.278
3	0.869	0.917
4	0.492	0.556
5	0.115	0.195
6	0.738	0.834
7	0.361	0.473
8	0.984	0.112

9	0.607	0.751

Table V

Table V shows that the phase introduced in the λ_2 and λ_3 configuration are approximately the same. There are 8 substantially different phases possible in the λ_2 and λ_3 configuration.

The single DVR lens, having NA=0.85, entrance pupil 4.0 mm and having a free working distance of 1.0 mm (see figure 1) (this design is used to illustrate the principle of the three-wavelength NPS, the tolerance of this lens are tight and therefore hard to manufacture) is tabulated in Appendix B (see below). In Table VI an NPS having 23 zones is tabulated showing a spherical wavefront for λ_2 and a spherical wavefront for λ_3.

The entrance pupil diameter for the DVD case is 2.85 mm with free working distance 0.796 mm and NA=0.6, while the entrance pupil diameter for the CD case is 2.118 mm with free working distance 0.445 mm and NA=0.45.

Figure 4 is a schematic illustration of an objective lens for use in the scanning device of Fig. 1 for operating in the first mode (here DVR configuration).

Figure 5 is a schematic illustration of an objective lens for use in the scanning device of Fig. 1 for operating in the second mode (here DVD configuration).

Figure 6 is a schematic illustration of an objective lens for use in the scanning device of Fig. 1 for operating in the third mode (here CD configuration).

Zones [mm]	h [µm]	m	$\Phi(\lambda_2,p_a)$	$\Phi(\lambda_3,p_c)$
0.000-0.230	0.000	0	0.000	0.000
0.230-0.320	4.050	5	0.723	1.225
0.320-0.400	1.620	2	1.546	1.747
0.400-0.470	5.670	7	2.268	2.972

0.470-0.530	3.240	4	3.091	3.493
0.530-0.580	0.810	1	3.914	4.015
0.580-0.640	4.860	6	4.637	5.240
0.640-0.690	2.430	3	5.460	5.762
0.690-0.750	6.480	8	6.183	6.987
0.750-0.820	4.050	5	7.006	7.508
0.820-0.900	1.620	2	7.829	8.030
0.900-1.150	-0.810	-1	8.652	8.551
1.150-1.205	1.620	2	7.829	–
1.205-1.240	4.050	5	7.006	–
1.240-1.270	6.480	8	6.183	–
1.270-1.295	2.430	3	5.460	–
1.295-1.315	4.860	6	4.637	–
1.315-1.335	0.810	1	3.914	–
1.335-1.352	3.240	4	3.091	–
1.352-1.368	5.670	7	2.268	–
1.368-1.380	1.620	2	1.546	–
1.380-1.395	4.050	5	0.723	–
1.395-1.325	0.000	3	-0.823	–

Table VI

Without the NPS the root mean square of the wavefront aberration (OPDrms) is in the DVR configuration 1.1 mλ, in the DVD configuration 466.8 mλ, in the CD configuration 202.5 mλ. With the NPS this becomes in the DVR configuration 1.1 mλ, in the DVD configuration 41.3 mλ, in the CD configuration 64.9 mλ. Hence

with the NPS present the wavefront aberration is in all configuration below the diffraction limit (70 mλ), allowing readout in all cases.

Third embodiment (or "embodiment 3") and fourth embodiment (or "embodiment 4")

The third and fourth embodiments relate to the cases where a step height h gives rise to the same phase in two of the three configurations. If this is the case two special embodiments are possible.

The third embodiment relates to the case where the step height h is chosen such that the phase introduced in the two configurations it equal to 2π. The stepped distribution of the NPS made of integer multiples of this height h will then have no effect for these two configurations. By proper design this structure can than select a predefined wavefront at the remaining third configuration.

The fourth embodiment relates to the case where the step height is chosen such that at the remaining third configuration a phase of 2π is generated. In this way we generate a flat wavefront at this configuration. At the other two configurations we can generate the same wavefront shape. The described explicit embodiment on the previous page is an example.

In respect of the third and fourth embodiments, the following requirement must be met. Choose λ_a as reference wavelength. We want to have that a height h introduces the same phase for the other two configurations λ_b and λ_c. Let n_a be the refractive index of the birefringent material for one polarisation and n_b be the refractive index of the birefringent material for the orthogonal polarisation. In order that a step height h introduces the same phase for the two configurations λ_b and λ_c we must have:

$$\frac{\lambda_b}{n_a - 1} = \frac{\lambda_c}{n_b - 1} \qquad (4)$$

From this it follows that n_b must be substantially be equal to

$$n_b = 1 + \frac{\lambda_c}{\lambda_b}(n_a - 1) \qquad (5)$$

With substantially equal we mean that the refractive index n in this polarisation must comply:

$$|n-n_b| \leq 0.05 \qquad (6)$$

In order to have an even better efficiencies it must comply with

$$|n-n_b| \leq 0.025 \qquad (7)$$

Example:

λ_b=650 nm and λ_c=785 nm and n_a=1.5, we find that n_b=1.604.

Finally, we note that when a step height h gives rise to a phase which is equal to 2π or an integer multiple of 2π in all three configurations it possible to design an NPS having no effect in all the three configurations. By switching one of the polarisations of the three laser it is possible to generate a predefined wavefront in this configuration. Applications for this is for instance switching the polarisation for the 405 nm laser resulting in a spherical aberration wavefront to compensate for the cover layer thickness for dual layer DVR applications.

Application area

The present invention can be used in other optical recording OPU employing non-periodic phase structures and three different wavelengths, different from the scanning device described with reference to Figs. 1 to 6. In particularly, the optical scanning device according to the present invention is particularly advantageous when considering DVR/DVD/CD compatibility, since it requires only one objective lens.

Appendix A: Precription data lens used in embodiment 1
System/Prescription Data

File : C:\ZEMAX\user\three_wavelengths\HD_DVD+DVD+CD+NPS1.zmx
Title:
Date : MON NOV 19 2001
Configuration 3 of 3

GENERAL LENS DATA:

Surfaces	: 17
Stop	: 11
System Aperture	: Float By Stop Size = 1.261
Glass Catalogs	: schott MISC USER
Ray Aiming	: Off
Apodization	:Uniform, factor = 0.00000E+000
Effective Focal Length	: 2.308764 (in air)

Effective Focal Length : 2.808764 (in image space)
Back Focal Length : -0.01294733
Total Track : 4.30383
Image Space F/# : 1.113707
Paraxial Working F/# : 1.113707
Working F/# : 1.100019
Image Space NA : 0.4095688
Object Space NA : 1.260998e-010
Stop Radius : 1.260998
Paraxial Image Height : 0
Paraxial Magnification : 0
Entrance Pupil Diameter : 2.521996
Entrance Pupil Position : 0
Exit Pupil Diameter : 2.524456
Exit Pupil Position : -2.824451
Field Type : Angle in degrees
Maximum Field : 0
Primary Wave : 0.785
Lens Units : Millimeters
Angular Magnification : 0

Fields : 1
Field Type: Angle in degrees

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY	VAN
1	0.000000	0.000000	0.000000	0.000000	0.000000

Wavelengths : 1
Units: Microns

#	Value	Weight
1	0.785000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	Infinity		0	0
1	COORDBRK		-	0	-	-	
2	USERSURF		2.093245	0		2.521996	-1
3	USERSURF		2.093245	0		2.521996	-1
4	USERSURF		2.093245	0		2.521996	-1
5	USERSURF		2.093245	0		2.521996	-1
6	USERSURF		2.093245	0		2.521996	-1
7	USERSURF		2.093245	0		2.521996	-1
8	USERSURF		2.093245	0		2.521996	-1
9	USERSURF		2.093245	0		2.521996	-1
10	USERSURF		2.093245	0		2.521996	-1
STO	EVENASPH		2.093245	0.017	DIACRYL	2.521996	-1
12	STANDARD		2.280003	2.395016	LAFN28	4	0
13	STANDARD		Infinity	0.6918145		4	0
14	COORDBRK		-	0	-	-	
15	STANDARD		Infinity	1.2	PC	3	0
16	STANDARD		Infinity	0		3	0
IMA	STANDARD		Infinity			0.01378555	0

SURFACE DATA DETAIL:

Surface OBJ : STANDARD

Surface 1 : COORDBRK
Decenter X : 0
Decenter Y : 0
Tilt About X : 0
Tilt About Y : 0
Tilt About Z : 0
Order : Decenter then tilt
Surface 2 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0
ROut: 0
Order #: 1
Const. ph. term: 0
Surface 3 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0
ROut: 0.4
Order #: 1
Const. ph. term: 0
Surface 4 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.4
ROut: 0.59
Order #: 1
Const. ph. term: 0
Surface 5 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0

16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.59
ROut: 1.1
Order #: 1
Const. ph. term: 0
Surface 6 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.1
ROut: 1.2
Order #: 1
Const. ph. term: 0
Surface 7 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.2
ROut: 1.26
Order #: 1
Const. ph. term: 0
Surface 8 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.26
ROut: 1.4
Order #: 1
Const. ph. term: 0
Surface 9 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0

16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.4
ROut: 1.55
Order #: 1
Const. ph. term: 0
Surface 10 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0.0050434889
6th Order Term: 7.3344175e-005
8th Order Term: -7.0483109e-005
10th Order Term: -4.7795094e-006
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.55
ROut: 1.65
Order #: 1
Const. ph. term: 0
Surface STO : EVENASPH
Coeff on r 2 : 0
Coeff on r 4 : 0.0050434889
Coeff on r 6 : 7.3344175e-005
Coeff on r 8 : -7.0483109e-005
Coeff on r 10 : -4.7795094e-006
Coeff on r 12 : 0
Coeff on r 14 : 0
Coeff on r 16 : 0
Aperture : Floating Aperture
Maximum Radius : 1.260998
Surface 12 : STANDARD
Aperture : Floating Aperture
Maximum Radius : 2
Surface 13 : STANDARD
Aperture : Floating Aperture
Maximum Radius : 2
Surface 14 : COORDBRK
Decenter X : 0
Decenter Y : 0
Tilt About X : 0
Tilt About Y : 0
Tilt About Z : 0
Order : Decenter then tilt
Surface 15 : STANDARD
Aperture : Floating Aperture
Maximum Radius : 1.5
Surface 16 : STANDARD
Aperture : Floating Aperture
Maximum Radius : 1.5
Surface IMA : STANDARD

COATING DEFINITIONS:

INDEX OF REFRACTION DATA:

Surf	Glass	Temp	Pres	0.785000
0		20.00	1.00	1.00000000
1	<CRD BRK>			1.00000000
2		20.00	1.00	1.00000000
3		20.00	1.00	1.00000000
4		20.00	1.00	1.00000000
5		20.00	1.00	1.00000000
6		20.00	1.00	1.00000000
7		20.00	1.00	1.00000000
8		20.00	1.00	1.00000000
9		20.00	1.00	1.00000000
10		20.00	1.00	1.00000000
11	DIACRYL	20.00	1.00	1.55877410
12	LAFN28	20.00	1.00	1.76248545
13		20.00	1.00	1.00000000
14	<CRD BRK>			1.00000000
15	PC	20.00	1.00	1.57308016
16		20.00	1.00	1.00000000
17		20.00	1.00	1.00000000

THERMAL COEFFICIENT OF EXPANSION DATA:

Surf	Glass	TCE *10E-6
0		0.00000000
1	<CRD BRK>	0.00000000
2		0.00000000
3		0.00000000
4		0.00000000
5		0.00000000
6		0.00000000
7		0.00000000
8		0.00000000
9		0.00000000
10		0.00000000
11	DIACRYL	142.80000000
12	LAFN28	5.80000000
13		0.00000000
14	<CRD BRK>	0.00000000
15	PC	0.00000000
16		0.00000000
17		0.00000000

ELEMENT VOLUME DATA:

Values are only accurate for plane and spherical surfaces.
Element volumes are computed by assuming edges are squared up to the larger of the front and back radial aperture.
Single elements that are duplicated in the Lens Data Editor for ray tracing purposes may be listed more than once yielding incorrect total mass estimates.

	Volume cc	Density g/cc	Mass g
Element surf 12 to 13	0.023521	4.240000	0.099730
Element surf 15 to 16	0.008482	1.000000	0.008482
Total Mass:		0.108212	

Appendix B

System/Prescription Data

File : C:\ZEMAX\user\three_wavelengths\DVR+DVD+CD+NPS1.zmx
Title:
Date : TUE NOV 20 2001
Configuration 1 of 3

GENERAL LENS DATA:

Surfaces : 29
Stop : 23
System Aperture : Entrance Pupil Diameter = 4
Glass Catalogs : schott MISC USER
Ray Aiming : Off
Apodization :Uniform, factor = 0.00000E+000
Effective Focal Length : 2.351466 (in air)
Effective Focal Length : 2.351466 (in image space)
Back Focal Length : 9.138515e-005
Total Track : 3.22
Image Space F/# : 0.5878665
Paraxial Working F/# : 0.5878665
Working F/# : 0.5884336
Image Space NA : 0.6478842
Object Space NA : 2e-010
Stop Radius : 2
Paraxial Image Height : 0
Paraxial Magnification : 0
Entrance Pupil Diameter : 4
Entrance Pupil Position : 0
Exit Pupil Diameter : 3.407863
Exit Pupil Position : -2.003277
Field Type : Angle in degrees
Maximum Field : 0
Primary Wave : 0.405
Lens Units : Millimeters
Angular Magnification : 0

Fields : 1
Field Type: Angle in degrees

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY	VAN
1	0.000000	0.000000	0.000000	0.000000	0.000000

Wavelengths : 1
Units: Microns

#	Value	Weight
1	0.405000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	Infinity		0	0
1	USERSURF		Infinity	0		4	0
2	USERSURF		Infinity	0		4	0
3	USERSURF		Infinity	0		4	0
4	USERSURF		Infinity	0		4	0
5	USERSURF		Infinity	0		4	0
6	USERSURF		Infinity	0		4	0

7	USERSURF	Infinity	0		4	0
8	USERSURF	Infinity	0		4	0
9	USERSURF	Infinity	0		4	0
10	USERSURF	Infinity	0		4	0
11	USERSURF	Infinity	0		4	0
12	USERSURF	Infinity	0		4	0
13	USERSURF	Infinity	0		4	0
14	USERSURF	Infinity	0		4	0
15	USERSURF	Infinity	0		4	0
16	USERSURF	Infinity	0		4	0
17	USERSURF	Infinity	0		4	0
18	USERSURF	Infinity	0		4	0
19	USERSURF	Infinity	0		4	0
20	USERSURF	Infinity	0		4	0
21	USERSURF	Infinity	0		4	0
22	USERSURF	Infinity	0		4	0
STO	EVENASPH	Infinity	2.12	LASFN31	4	-1
24	COORDBRK	-	0		-	-
25	EVENASPH	Infinity	0		2.75	-1
26	COORDBRK	-	1		-	-
27	STANDARD	Infinity	0.1	POLYCARB	4	0
28	STANDARD	Infinity	0		4	0
IMA	STANDARD	Infinity			0.002698454	0

SURFACE DATA DETAIL:

Surface OBJ : STANDARD
Surface 1 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.23
ROut: 0.32
Order #: 1
Const. ph. term: 0
Surface 2 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.32
ROut: 0.4
Order #: 1
Const. ph. term: 0
Surface 3 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0

6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.4
ROut: 0.47
Order #: 1
Const. ph. term: 0
Surface 4 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.47
ROut: 0.53
Order #: 1
Const. ph. term: 0
Surface 5 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.53
ROut: 0.58
Order #: 1
Const. ph. term: 0
Surface 6 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.58
ROut: 0.64
Order #: 1
Const. ph. term: 0
Surface 7 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0

6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.64
ROut: 0.69
Order #: 1
Const. ph. term: 0
Surface 8 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.69
ROut: 0.75
Order #: 1
Const. ph. term: 0
Surface 9 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.75
ROut: 0.82
Order #: 1
Const. ph. term: 0
Surface 10 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0,82
ROut: 0,9
Order #: 1
Const. ph. term: 0
Surface 11 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0

6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 0.9
ROut: 1.15
Order #: 1
Const. ph. term: 0
Surface 12 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.15
ROut: 1.205
Order #: 1
Const. ph. term: 0
Surface 13 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.205
ROut: 1.24
Order #: 1
Const. ph. term: 0
Surface 14 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.24
ROut: 1.27
Order #: 1
Const. ph. term: 0
Surface 15 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0

6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.27
ROut: 1.295
Order #: 1
Const. ph. term: 0
Surface 16 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.295
ROut: 1.315
Order #: 1
Const. ph. term: 0
Surface 17 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.315
ROut: 1.335
Order #: 1
Const. ph. term: 0
Surface 18 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.335
ROut: 1.352
Order #: 1
Const. ph. term: 0
Surface 19 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0

6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.352
ROut: 1.368
Order #: 1
Const. ph. term: 0
Surface 20 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.368
ROut: 1.38
Order #: 1
Const. ph. term: 0
Surface 21 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.38
ROut: 1.395
Order #: 1
Const. ph. term: 0
Surface 22 : USERSURF (ANNLBIN2.DLL)
2nd Order Term: 0
4th Order Term: 0
6th Order Term: 0
8th Order Term: 0
10th Order Term: 0
12th Order Term: 0
14th Order Term: 0
16th Order Term: 0
Max Term #: 1
Norm Radius: 1
RIn: 1.41
ROut: 1.425
Order #: 1
Const. ph. term: 0
Surface STO : EVENASPH
Coeff on r 2 : 0.27025467
Coeff on r 4 : 0.013621503

Coeff on r 6 : 0.0010887228
Coeff on r 8 : 0.00025122383
Coeff on r 10 : -5.8150037e-005
Coeff on r 12 : 2.1911964e-005
Coeff on r 14 : -1.965101e-006
Coeff on r 16 : 0
Surface 24 : COORDBRK
Decenter X : 0
Decenter Y : 0
Tilt About X : 0
Tilt About Y : 0
Tilt About Z : 0
Order : Decenter then tilt
Surface 25 : EVENASPH
Coeff on r 2 : 0.085615362
Coeff on r 4 : 0.029034441
Coeff on r 6 : -0.031174254
Coeff on r 8 : 0.02322335
Coeff on r 10 : -0.012032137
Coeff on r 12 : 0.0035665564
Coeff on r 14 : -0.00044658898
Coeff on r 16 : 0
Aperture : Floating Aperture
Maximum Radius : 1.375
Surface 26 : COORDBRK
Decenter X : 0
Decenter Y : 0
Tilt About X : 0
Tilt About Y : 0
Tilt About Z : 0
Order : Decenter then tilt
Surface 27 : STANDARD
Aperture : Floating Aperture
Maximum Radius : 2
Surface 28 : STANDARD
Aperture : Floating Aperture
Maximum Radius : 2
Surface IMA : STANDARD

COATING DEFINITIONS:

INDEX OF REFRACTION DATA:

Surf	Glass	Temp	Pres	0.405000
0		20.00	1.00	1.00000000
1		20.00	1.00	1.00000000
2		20.00	1.00	1.00000000
3		20.00	1.00	1.00000000
4		20.00	1.00	1.00000000
5		20.00	1.00	1.00000000
6		20.00	1.00	1.00000000
7		20.00	1.00	1.00000000
8		20.00	1.00	1.00000000
9		20.00	1.00	1.00000000
10		20.00	1.00	1.00000000
11		20.00	1.00	1.00000000
12		20.00	1.00	1.00000000

13		20.00	1.00	1.00000000
14		20.00	1.00	1.00000000
15		20.00	1.00	1.00000000
16		20.00	1.00	1.00000000
17		20.00	1.00	1.00000000
18		20.00	1.00	1.00000000
19		20.00	1.00	1.00000000
20		20.00	1.00	1.00000000
21		20.00	1.00	1.00000000
22		20.00	1.00	1.00000000
23	LASFN31	20.00	1.00	1.91811491
24	<CRD BRK>			1.91811491
25		20.00	1.00	1.00000000
26	<CRD BRK>			1.00000000
27	POLYCARB	20.00	1.00	1.62230752
28		20.00	1.00	1.00000000
29		20.00	1.00	1.00000000

THERMAL COEFFICIENT OF EXPANSION DATA:

Surf	Glass	TCE *10E-6
0		0.00000000
1		0.00000000
2		0.00000000
3		0.00000000
4		0.00000000
5		0.00000000
6		0.00000000
7		0.00000000
8		0.00000000
9		0.00000000
10		0.00000000
11		0.00000000
12		0.00000000
13		0.00000000
14		0.00000000
15		0.00000000
16		0.00000000
17		0.00000000
18		0.00000000
19		0.00000000
20		0.00000000
21		0.00000000
22		0.00000000
23	LASFN31	6.80000000
24	<CRD BRK>	6.80000000
25		0.00000000
26	<CRD BRK>	0.00000000
27	POLYCARB	67.00000000
28		0.00000000
29		0.00000000

ELEMENT VOLUME DATA:

Values are only accurate for plane and spherical surfaces.
Element volumes are computed by assuming edges are squared up to the larger of the front and back radial aperture.
Single elements that are duplicated in the Lens Data Editor for ray tracing purposes may be listed more than once yielding incorrect total mass estimates.

	Volume cc	Density g/cc	Mass g
Element surf 27 to 28	0.001257	1.250000	0.001571
Total Mass:		0.001571	

CLAIMS

1. An optical scanning device for scanning a first information layer, a second information layer and a third information layer by means of a first radiation beam having a first wavelength λ_1, a second radiation beam having a second wavelength λ_2, and a third radiation beam having a third wavelength λ_3, respectively, said first, second and third wavelengths being substantially mutually different, the device comprising:

a radiation source for emitting said first, second and third radiation beams,

an objective system for converging said first, second and third radiation beams beam on the positions of said first, second and third information layers, and

a phase structure arranged in the optical path of said first, second and third radiation beams between said radiation source and the positions of said first, second and third information layers, the phase structure comprising a plurality of phase elements of different heights, forming a non-periodic stepped profile of optical paths in the beam,

characterised in that said phase structure is made of a birefringent material and in that said stepped profile is designed so as to introduce a wavefront modification in at least one of said first, second and third radiation beams and such that at least two of said first, second and third radiation beams have mutually different polarizations.

2. The scanning device according to Claim 1, wherein said wavefront modification is of the type of spherical aberration.

3. The scanning device according to Claim 1, wherein said stepped profile substantially approximates a flat wavefront at said first wavelength, a spherical aberration wavefront at said second wavelength, and a spherical aberration wavefront or a flat wavefront at said third wavelength.

4. The scanning device according to Claim 1, wherein $|\lambda_1-\lambda_2|$, $|\lambda_2-\lambda_3|$ and $|\lambda_1-\lambda_3|$ are each larger than 10 nm.

5. The scanning device according to Claim 1, wherein $|\lambda_1-\lambda_2|$, $|\lambda_2-\lambda_3|$ and $|\lambda_1-\lambda_3|$ are each larger than 20 nm.

6. The scanning device according to Claim 1, wherein the differences in length between the optical paths at the first wavelength λ_1 correspond to phase changes in the beam substantially equal to multiples of 2π.

7. The scanning device according to Claim 1, wherein the phase structure is generally circular and the steps of said stepped profile are generally annular.

8. The scanning device according to Claim 1, wherein said phase structure is formed on a face of a lens of the objective system.

9. The scanning device according to Claim 1, wherein said phase structure is formed on an optical plate provided between the radiation source and the objective system.

10. The scanning device according to Claim 9, wherein said optical plate comprises a quarter wavelength plate or a beam splitter.

11. A lens for use in an optical device for scanning a first, second and third type of optical record carrier with a beam of radiation of a first wavelength λ_1, a second wavelength λ_2 and a third wavelength λ_3, respectively, the three wavelengths being substantially different, the lens being provided with a phase structure arranged in the path of the radiation beam, the phase structure comprising a plurality of phase elements of different heights, forming a non-periodic stepped profile of optical paths in the beam,
characterised in that said phase structure is made of a birefringent material and in that said stepped profile is designed so as to introduce a wavefront modification in at least one of said first, second and third radiation beams and such that at least two of said first, second and third radiation beams have mutually different polarizations.

ABSTRACT:

An optical scanning device for scanning three information layers with three radiation beams having three substantially different wavelengths, the device comprising: (a) a radiation source for emitting the radiation beams, (b) an objective system for converging the three radiation beams beam on the positions of the three respective information layers, and (c) a phase structure arranged in the optical path of the radiation beams between the radiation source and the information layers, the phase structure comprising a plurality of phase elements of different heights, forming a non-periodic stepped profile of optical paths in the beam. According to the invention, said phase structure is made of a birefringent material and in that said stepped profile is designed so as to introduce a wavefront modification in at least one of said first, second and third radiation beams and such that at least two of said first, second and third radiation beams have mutually different polarizations.

Figure 1

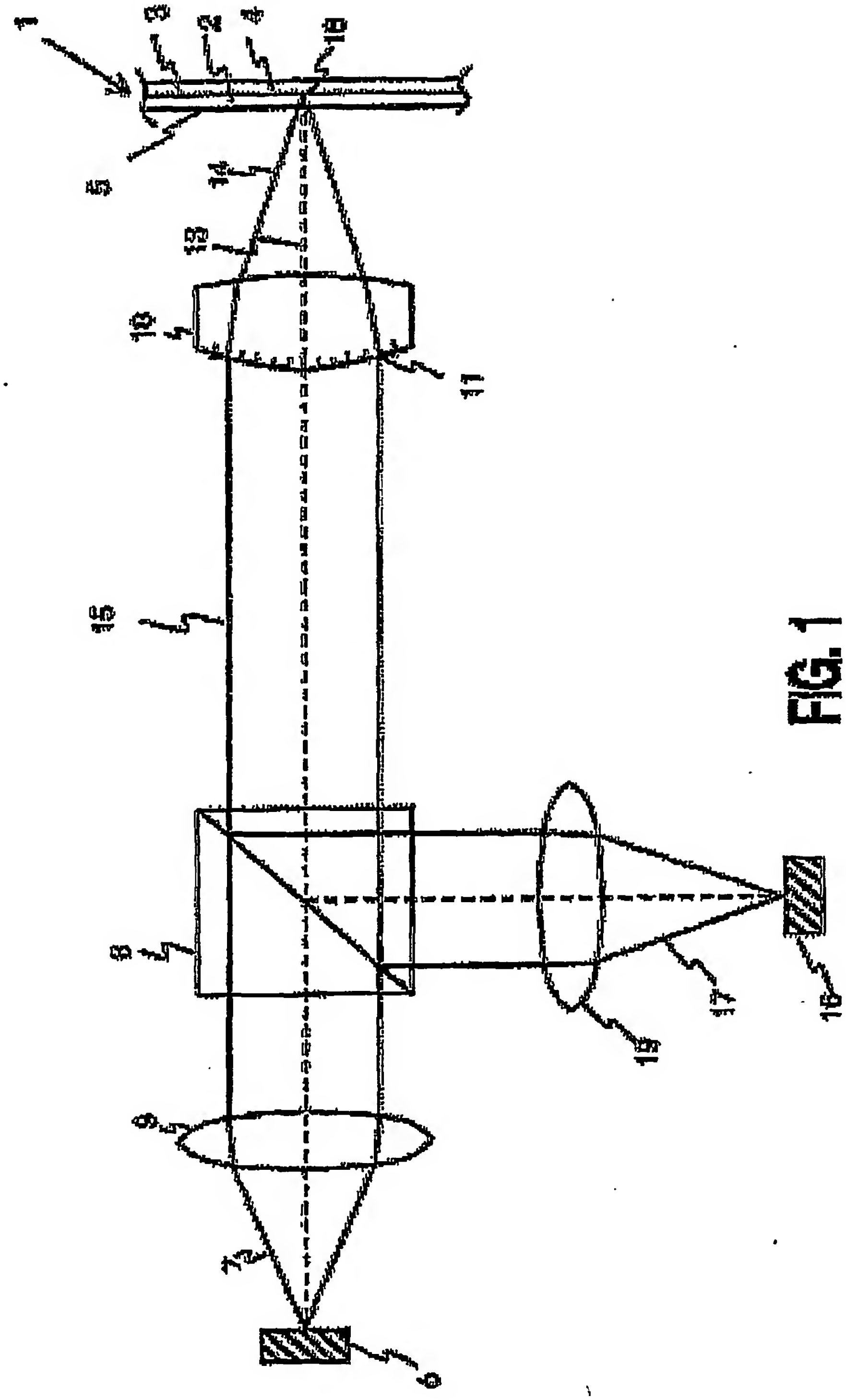

FIG. 1

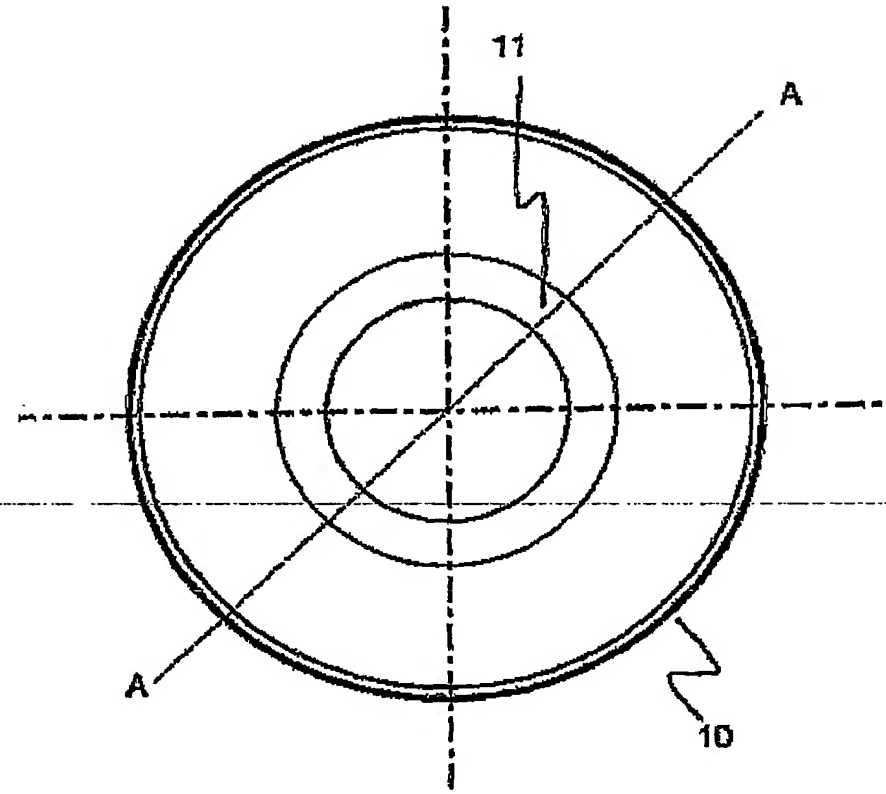

Fig. 2

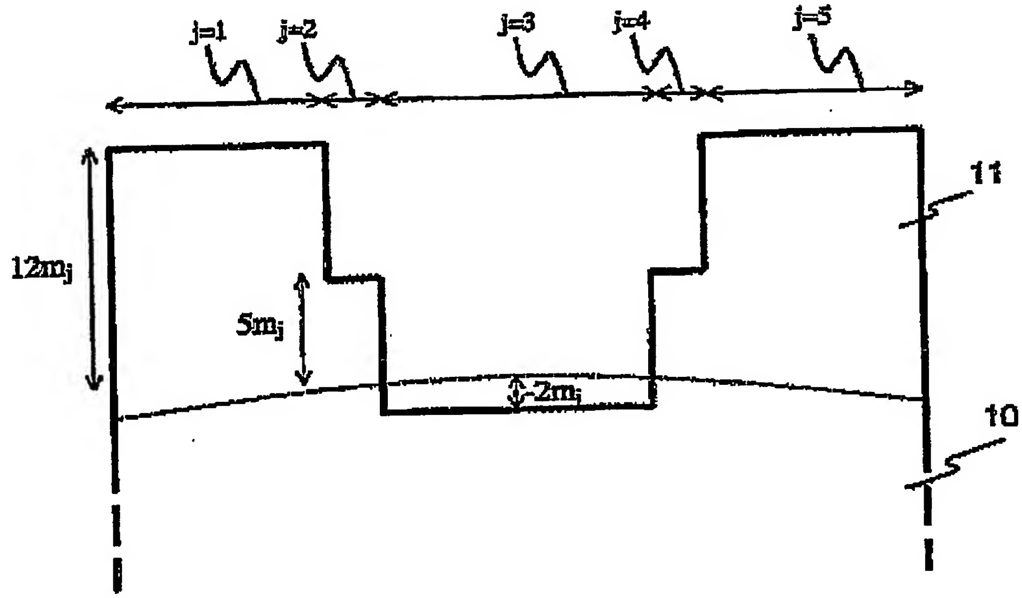

Fig. 3 (A-A)

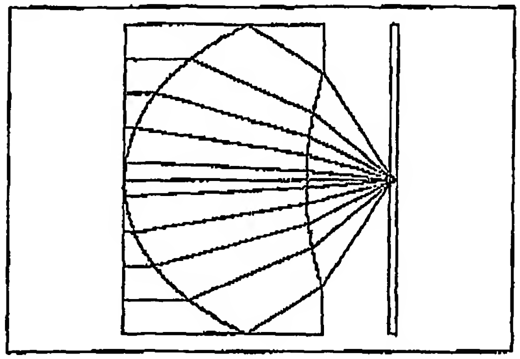

Fig. 4

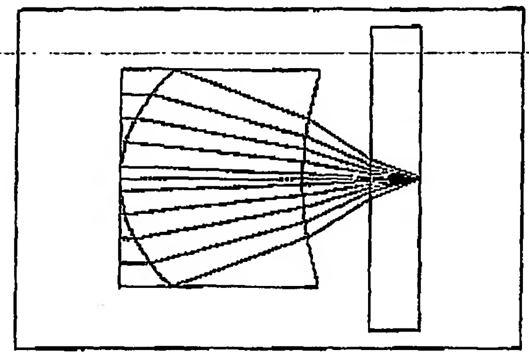

Fig. 5

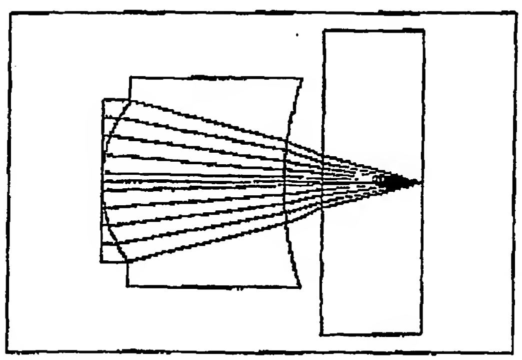

Fig. 6